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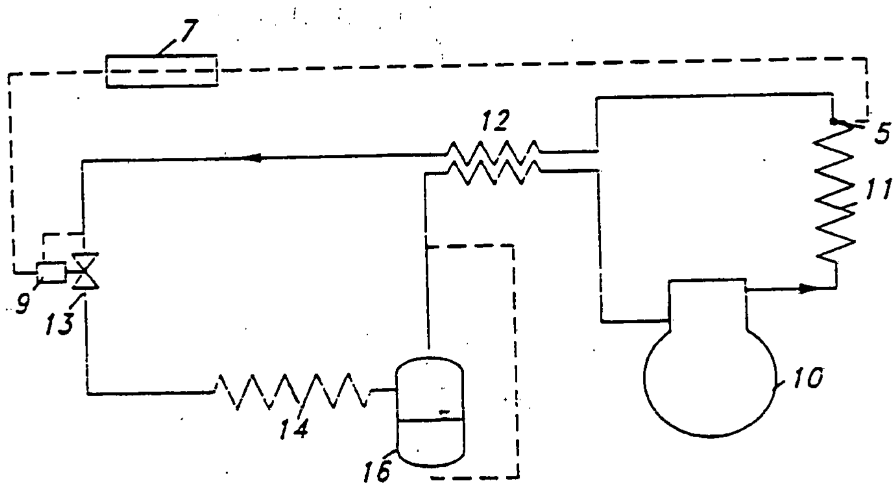
*With amended claims and statement.*

(54) Title: METHOD OF HIGH-SIDE PRESSURE REGULATION IN TRANSCRITICAL VAPOR COMPRESSION CYCLE DEVICE




(57) Abstract

A vapor compression cycle device operating at supercritical pressure in the high-side of a circuit comprising compressor (10), gas cooler (11), internal heat exchanger (12), throttling valve (13), evaporator (14), low pressure refrigerant receiver is additionally provided with means (5) for detection of at least one operating condition of the circuit, preferentially detection of a parameter representing the refrigerant temperature adjacent to the outlet of the gas cooler (11).

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# Method of high-side pressure regulation in transcritical vapor compression cycle device

## Field of the Invention

The present invention relates to vapor compression cycle devices such as refrigerating, air-conditioning and heat pump systems, operating under transcritical conditions, and more particularly to a method of high-side pressure regulation maintaining optimum operation with respect to energy consumption.

## Background of the Invention

A co-pending PCT application, publication No. WO 90/07683, discloses a transcritical vapor compression cycle device and a method for regulating its capacity based on modulation of the supercritical high-side pressure. The system consists of a compressor, a gas cooler (condenser), an internal heat exchanger, an evaporator and a receiver. Capacity control is achieved by varying the liquid inventory of the low pressure refrigerant receiver situated intermediate the evaporator and the compressor, where a throttling valve between the high pressure outlet of the internal heat exchanger and evaporator inlet is applied as steering means.

Excessive tests conducted recently on a prototype of the transcritical vapor compression unit show that for some specific applications of the invention, e.g. in mobile air-conditioning units working at varying loads and conditions, the high-side pressure at less than full capacity should be adjusted in accordance with the actual operating conditions (load) of the unit, in order to achieve minimum energy consumption at the given capacity requirement. The actual operating conditions may be defined by refrigerant temperatures or pressures, by external temperatures or by the capacity requirements. Any available state-of-the-art capacity control system, e.g. on/off, variable capacity compressor or variable speed control, can be used separately and independently of the throttling valve steering in the disclosed circuit to regulate the cooling or heating capacity. Consequently, it was necessary to develop a new throttling valve control strategy to obtain optimal operation with respect to energy consumption of the disclosed vapor compression device.

## Object of the Invention

It is therefore an object of the present invention to provide a new simple method and means for regulating the high-side pressure in a transcritical vapor compression circuit to achieve minimum energy consumption and optimum operation of the system.

## Summary of the Invention

The above and other objects of the present invention are achieved by provision of a steering strategy for the throttling valve in the transcritical vapor compression circuit based on application of predetermined values of optimal high-side

pressure corresponding to the detected actual operating conditions of the circuit. In a preferred embodiment of the invention, the detection of the operating conditions is done by measurement of a temperature at or near the gas cooler (condenser) outlet, and the valve position is modulated to the predetermined set-point pressure by an appropriate control system.

**Brief description of the drawings**

The invention is described in more details by means of preferred embodiments and referring to the attached drawings, Figs. 1-3, where

Fig. 1 is a graph illustrating the theoretical relationship between cooling capacity ($Q_o$), compressor shaft power (P) and their ratio (COP) in the transcritical vapor compression cycle at varying high-side pressure, at constant evaporating temperature and gas cooler (condenser) outlet refrigerant temperature,

Fig. 2 is a graphic illustration of the theoretical relationship between optimum high-side pressure, providing maximum ratio between cooling capacity and shaft power, and gas cooler (condenser) outlet refrigerant temperature at three different evaporating temperatures, and

Fig. 3 is a schematic representation of a transcritical vapor compression cycle device constructed in accordance with a preferred embodiment of the invention.

## Detailed description of the Invention

A well known peculiarity of transcritical cycles (operating with the refrigerant compressed to a supercritical pressure in the high-side) is that the coefficient of performance COP, defined as the ratio between the refrigerating capacity and applied compressor shaft power, can be raised by increasing the high-side pressure, while the gas cooler (condenser) outlet refrigerant temperature is maintained mainly constant. This can be illustrated by means of a conventional pressure enthalpy diagram. However, the COP increases with increasing high-side pressure only up to a certain level and then begins to decline as the extra refrigerating effect no longer fully compensates for the extra work of compression.

Thus, for each set of actual operating conditions defined for instance by evaporating temperature and refrigerant temperature at the gas cooler (condenser) outlet, a diagram showing the cooling capacity ($Q_0$), compressor shaft power (P) and their ratio (COP) as a function of high-side pressure can be provided. Fig. 1 illustrates such a diagram generated for refrigerant $CO_2$ at a constant evaporating and gas cooler (condenser) outlet temperature, based on theoretical cycle calculations. At a certain high-side pressure corresponding to p' in Fig. 1, the COP reaches a maximum as indicated.

By combining such results, i.e. corresponding data for gas cooler (condenser) outlet refrigerant temperature, evaporating temperature and high-side pressure providing maximum COP (p'), at varying operating conditions, a new set of data, as shown in Fig. 2, is provided, which may be applied in the throttling valve steering strategy. By regulating the high-side pressure in accordance with this diagram, a maximum ratio between refrigerating capacity and compressor shaft power will always be maintained.

Under maximum load conditions it still may be expedient to operate the system at a discharge pressure well above the level corresponding to maximum COP for a shorter period of time, to limit the compressor volume required and thereby the capital cost and overall energy consumption. At low load conditions, however, a combination of reduced high-side pressure to a predetermined optimum level and capacity regulation conducted by a separate control system will provide minimum energy consumption.

Since varying evaporating temperature has a noticeable effect only at high gas cooler (condenser) outlet refrigerant temperature, this influence may be neglected in practice. Thus the detected refrigerant temperature at the gas cooler (condenser) outlet or some other temperature or parameter corresponding to this (e.g. cooling water inlet temperature, ambient air temperature, cooling or heating load) will be the only significant steering parameter required as input for control of the throttling valve.

The use of a back-pressure controller as throttling valve may give certain advantages in that internal compensation for varying refrigerant mass flow and density is obtained. A throttling valve with back-pressure control will keep the inlet pressure, i.e. high-side pressure, at the set point regardless of refrigerant mass flow and inlet refrigerant temperature. The set-point of the back-pressure controller is then regulated by means of an actuator operating in accordance with the predetermined control scheme indicated above.

<u>Example 1</u>

Fig. 3 illustrates a preferred embodiment of the transcritical refrigerating circuit comprising a compressor 10 connected in series to a gas cooler (condenser) 11, an internal counterflow

heat exchanger 12 and a throttling valve 13. An evaporator 14 and a low pressure liquid receiver 16 are connected intermediate the throttling valve and the compressor. A temperature sensor at the gas cooler (condenser) refrigerant outlet 5 provides information on the operating conditions of the circuit to the control system 7 e.g. a microprosessor. The throttling valve 13 is equipped with an actuator 9 and the valve position is automatically modulated in accordance with the predetermined set-point pressure characteristics by the control system.

Example 2

Referring to Figure 3 the circuit is now provided with a throttling valve 13 based on a simple mechanical back-pressure controller eliminating use of the microprocessor and electronic control of the valve shown in Example 1. The regulator is equipped with a temperature sensor bulb 5 situated at or near the gas cooler (condenser) refrigerant outlet.

Through a membrane arrangement, the pressure resulting from the sensor bulb temperature mechanically adjusts the set-point of the back-pressure controller according to the gas cooler (condenser) outlet refrigerant temperature. By adjusting spring forces and charge in the sensor 5 an appropriate relation between the temperature and pressure in the actual regulation range may be obtained.

Example 3

The circuit is based on one of the throttling valve control concepts described in Examples 1 or 2, but instead of locating the temperature sensor or sensor bulb at the gas cooler

(condenser) refrigerant outlet, the sensor or sensor bulb measures the inlet temperature of the cooling agent to which heat is rejected. By counterflow heat exchange, there is a relation between gas cooler (condenser) refrigerant outlet and cooling medium inlet temperatures, as the refrigerant outlet temperature closely follows the cooling medium inlet temperature. The applied cooling medium is normally ambient air or cooling water.

While the invention has been illustrated and described in the drawings and foregoing description in terms of preferred embodiments it is apparent that changes and modifications may be made therein without departing from the spirit or scope of the invention as set forth in the appended claims. Thus, e.g. in any of the concepts described in Examples 1 or 2, the signal from a temperature sensor or bulb may be replaced by a signal representing the desired cooling or heating capacity of the system. Due to the correspondence between ambient temperature and load, this signal may serve as a basis for regulating throttling valve set-point pressure.

# Claims

1. Method of modulating high-side pressure in a trans-critical vapor compression device comprising a compressor (10), a gas cooler (11), an internal heat exchanger (12), a throttling valve (13), an evaporator (14) and a low pressure refrigerant receiver (16) connected in series into a circuit,
c h a r a c t e r i z e d i n t h a t
the method comprises steps of detecting at least one of the actual operating conditions of the circuit and modulation of the throttling valve position in accordance with a predetermined set of high pressure values to achieve minimum energy consumption of the device at given capacity requirements.

2. Method according to claim 1,
c h a r a c t e r i z e d i n t h a t
the detection of the operating conditions is conducted by measurement of the refrigerant temperature adjacent an outlet of the gas cooler.

3. A method according to claim 1 or 2
c h a r a c t e r i z e d i n t h a t
carbon dioxide is applied as a refrigerant.

4. A vapor compression cycle device operating at super-critical pressure in the high-side and comprising a compressor (10), a gas cooler (11), an internal heat exchanger (12), a throttling valve (13), an evaporator (14) and a low pressure refrigerant receiver (16) connected in series into a circuit,

c h a r a c t e r i z e d i n t h a t
the device further comprises means (5) for detecting at least one operating condition of the circuit and control means (9), operatively connected to the detecting means and to the throttling valve, for controlling the degree of opening of the throttling valve as a function of the detected operating condition in accordance with a predetermined set of high pressure values to achieve minimum energy consumption at given capacity requirements.

5. Device according to claim 4,
c h a r a c t e r i z e d i n t h a t
the detecting means (5) comprises means for measuring a parameter representative of the refrigerant temperature adjacent an outlet of the gas cooler.

6. Device according to claim 4 or 5,
where the throttling valve (13) is a back-pressure controlling unit with variable set-point electronically controlled by a microprosessor (7).

7. Device according to claim 5,
where the throttling valve (13) is a back-pressure controlling unit with variable set-point comprising a temperature sensor bulb situated at or near the gas cooler refrigerant outlet or at another location having a temperature representing the operating condition of the circuit, and a membrane arrangement regulating the set-point of the back-pressure controlling unit in a desired relation to the bulb temperature.

AMENDED CLAIMS

[received by the International Bureau on 12 January 1993 (12.01.93); original claims 1 and 4 amended; remaining claims unchanged (2 pages)]

1. Method of modulating high-side pressure in a trans-critical vapor compression device operating with super-critical high-side pressure and comprising a com-pressor, a gas cooler, an internal heat exchanger, an expansion means, an evaporator and a low pressure refrigerant
receiver connected in series into a circuit,
c h a r a c t e r i z e d i n t h a t
the method comprises steps of detecting at least one of the actual operating conditions of the circuit and modulation of the supercritical high-side pressure in accordance with a predetermined set of values to achieve minimum energy consumption of the device at given capacity requirements.

2. Method according to claim 1,
c h a r a c t e r i z e d i n t h a t
the detection of the operating conditions is conducted by measurement of the refrigerant temperature adjacent an outlet of the gas cooler.

3. A method according to claim 1 or 2
c h a r a c t e r i z e d i n t h a t
carbon dioxide is applied as a refrigerant.

4. A vapor compression cycle device operating at super-critical pressure in the high-side and comprising a compressor (10), a gas cooler (11), an internal heat exchanger (12), a throttling valve (13), an evaporator (14) and a low pressure refrigerant receiver (16) con-nected in series into a circuit,

c h a r a c t e r i z e d i n t h a t
the device further comprises means (5) for detecting at least one operating condition of the circuit and control means (9), operatively connected to the detecting means (5) and to the throttling valve, for modulation of the supercritical high-side pressure by controlling the degree of opening of the throttling valve as a function of the detected operating condition in accordance with a predetermined set of high pressure values.

5. Device according to claim 4,
c h a r a c t e r i z e d i n t h a t
the detecting means (5) comprises means for measuring a parameter representative of the refrigerant temperature adjacent an outlet of the gas cooler.

6. Device according to claim 4 or 5,
where the throttling valve (13) is a back-pressure controlling unit with variable set-point electronically controlled by a microprosessor (7).

7. Device according to claim 5,
where the throttling valve (13) is a back-pressure controlling unit with variable set-point comprising a temperature sensor bulb situated at or near the gas cooler refrigerant outlet or at another location having a temperature representing the operating condition of the circuit, and a membrane arrangement regulating the set-point of the back-pressure controlling unit in a desired relation to the bulb temperature.

# Statement under Artice 19(1)

The actual amendments of claims 1 and 4 are made in order to more distinctly define our present invention compared to the conventional systems where expansion/throttling valves are applied for controlling the refrigerant flow to the evaporator by varying the valve position. The subcritical, high-side pressure in conventional systems is not directly affected by the throttling valve position.

In the present transcritical system the throttling valve is applied for control of the supercritical high-side pressure at substantially constant refrigerant flow.

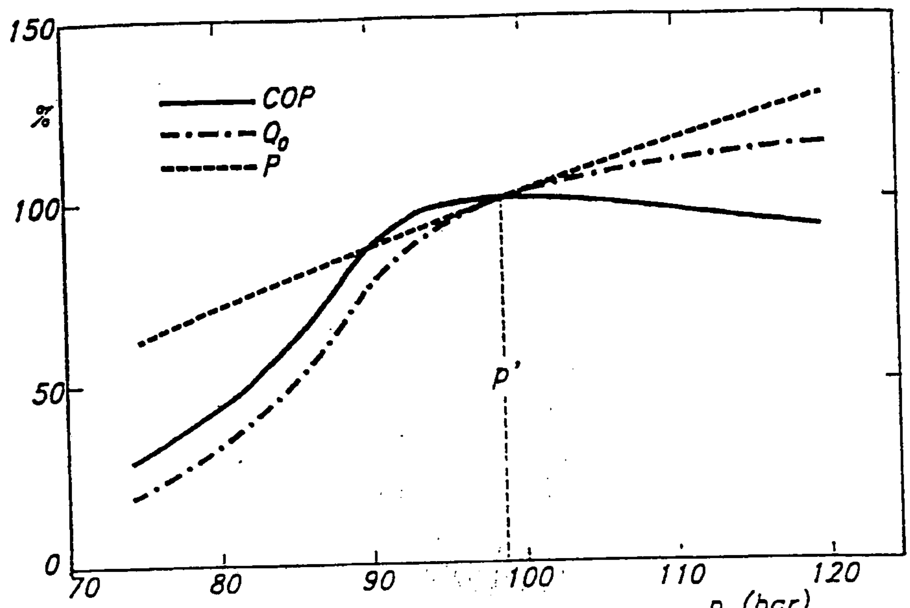
150
%
COP
$Q_0$
P
100
50
0
p'
70
80
90
100
110
120
p (bar)

Fig. 1

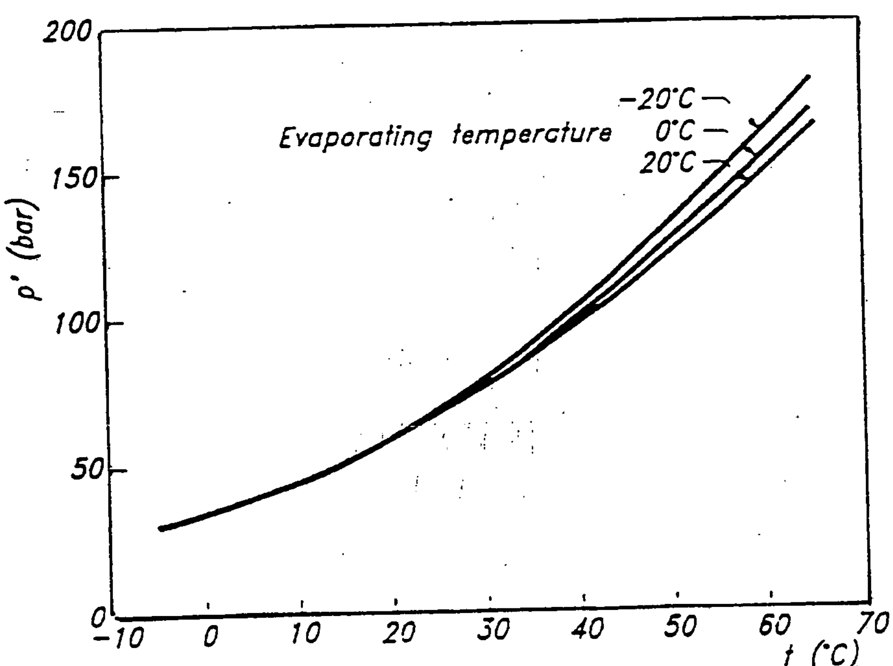
200
150
100
50
0
p' (bar)
Evaporating temperature
-20°C
0°C
20°C
-10
0
10
20
30
40
50
60
70
t (°C)

Fig. 2

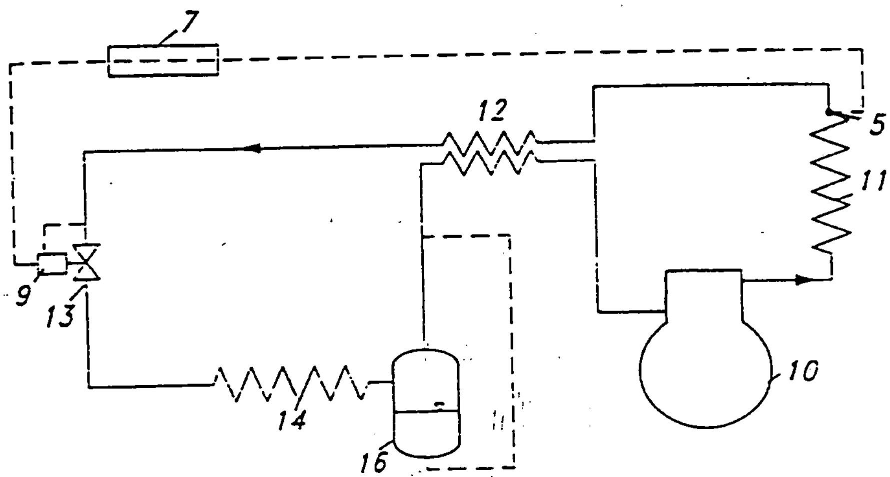


Fig. 3

# INTERNATIONAL SEARCH REPORT

International Application No PCT/NO 91/00119

**I. CLASSIFICATION OF SUBJECT MATTER** (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: F 25 B 41/06, F 25 B 1/00, F 25 B 30/02

**II. FIELDS SEARCHED**

Minimum Documentation Searched[7]

| Classification System | Classification Symbols |
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| IPC5 | F 25 B |

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched[8]

SE,DK,FI,NO classes as above

**III. DOCUMENTS CONSIDERED TO BE RELEVANT**[9]

| Category * | Citation of Document,[11] with indication, where appropriate, of the relevant passages[12] | Relevant to Claim No.[13] |
|---|---|---|
| Y | WO, A1, 9007683 (SINVENT AS) 12 July 1990, see page 7, column 3; page 10; page 12, column 4 - column 5; figure 2 -- | 1-5 |
| Y | US, A, 1591302 (W.S. FRANKLIN) 6 July 1926, see page 1, line 43 - line 81; figure 1 -- | 1-5 |
| Y | SE, B, 463533 (HANDELSBOLAGET HELIOVENT) 14 October 1988, see page 3, line 31 - page 5; figure 2 -- | 1-5 |
| A | US, A, 3638446 (PALMER) 1 February 1972, see page 1, line 25 - line 44; figure 1 -- | 1-7 |

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**IV. CERTIFICATION**

| Date of the Actual Completion of the International Search | Date of Mailing of this International Search Report |
|---|---|
| 27th April 1992 | 1992 -04- 30 |
| **International Searching Authority** | **Signature of Authorized Officer** |
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| A | US, A, 4205532 (BRENAN) 3 June 1980, see the whole document -- | 1-7 |
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## ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.PCT/NO 91/00119

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
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| US-A- 3413815 | 68-12-03 | NONE | | |